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Distributed energy resources and benefits to the environment

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ABSTRACT

The recently released report of the International Energy Outlook (IEO2009) projects an increase of 44% in the world energy demand from 2006 to 2030, and 77% rise in the net electricity generation worldwide in the same period. However, threatening in the said report is that 80% of the total generation in 2030 would be produced from fossil fuels. This global dependence on fossil fuels is dangerous to our environment in terms of their emissions unless specific policies and measures are put in place. Nevertheless, recent research reveals that a reduction in the emissions of these gases is possible with widespread adoption of distributed generation (DG) technologies that feed on renewable energy sources, in the generation of electric power. This paper gives a detailed overview of distributed energy resources technologies, and also discusses the devastating impacts of the conventional power plants feeding on fossil fuels to our environment. The study finally justifies how DG technologies could substantially reduce greenhouse gas emissions when fully adopted; hence, reducing the public concerns over human health risks caused by the conventional method of electricity generation.

Contents

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1. Introduction

The energy report of the International Energy Outlook 2009 (IEO2009) [1] published in May 2009 is a serious source of concern in the power production circle. Expectedly though, there is an increase in the projection of future electricity demand across the globe. The said report reveals that the world energy demand increases from 472 quadrillion Btu in 2006 to 552 quadrillion Btu and 678 quadrillion Btu in 2015 and in 2030, respectively, see Fig. 1. This is a total increase of 44% over the projection period. While net electricity generation worldwide totals 31.8 trillion kW h in 2030 in the reference case. This is 77% higher than the 2006 total of 18.0 trillion kW h. However, the threatening aspect of the report is the worldwide over-dependence on fossil fuels (oil, coal and natural gas) for electricity generation.

With the projection of 80% of the total power generation in year 2030 coming from fossil fuels, it follows that global greenhouse gas (GHG) emissions will rise further causing an increase to the surface temperature which will lead to irreversible and possibly catastrophic changes to the earth's environment. Given this scenario, the challenge before all nations especially the industrialized ones, is the global reduction in CO_2 emissions by between 50% and 80% by 2050, since it is the principal gas responsible for global warming [2]. Failure to achieve the target may result in the universe becoming a dangerous place to live.

Really, it is generally anticipated that traditional fossil fuels would be phased out over time by renewable energy sources. The reason is majorly due to the global concerns over the amount of GHGs emitted to the atmosphere when these fuels are burnt for one purpose or another. These gases trap heat in the atmosphere and prevent it from escaping to space, thereby resulting to global warming which could lead to world climate change. This is why governments and regulatory agencies at various levels have adopted specific policies to support renewable energy as alternative energy sources. Government policies and incentives typically are the primary drivers for the construction of renewable generation facilities.

The clean development mechanism (CDM) is one of the three flexible mechanisms established by the Kyoto Protocol. Others are international emissions trading (IET) and joint implementation (JI). The primary purposes of the CDM are:

(i) To assist Parties not listed in Annex I to achieve sustainable development and hence, contribute to the ultimate objective of the Convention in climate change.
(ii) To assist Parties included in Annex I in achieving compliance with their quantified emissions limitation and reduction commitments.

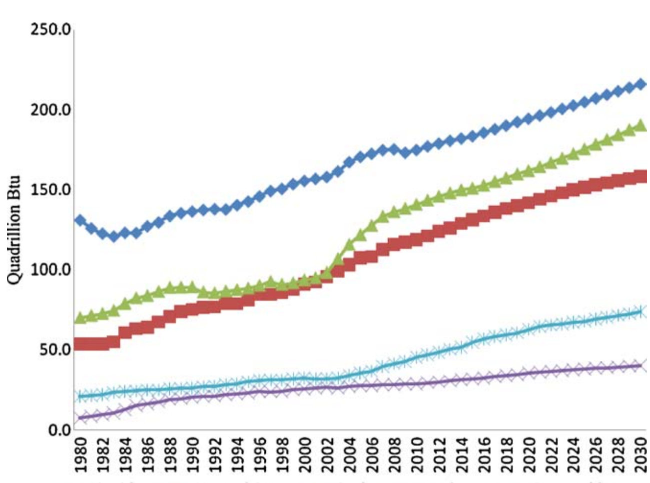

Fig. 1. Historical and projected world energy demand by fuels.

To achieve these laudable objectives, projects to reduce GHG emissions will be implemented in non-Annex I countries. It is expected that Annex I Parties would contribute financing, technology transfer, and other necessary support for the projects. The increased flow of these resources to developing countries is intended in principle to support their sustainable development, while at the same time reducing the global GHG emissions since it is becoming practically impossible to achieve this in their own countries. Installation of DG could be a viable project that Annex I Parties could embark upon to assist most developing countries since it is glaringly evident that epileptic electric power supply has always being the bane of development in these countries. However, recent studies have revealed that CDM has not been able to achieve its purpose as mandated by Kyoto Protocol since its birth in 1997 due to certain factors [3].

On the other hand, recent studies have revealed that widespread adoption of distributed generation (DG) technologies in power systems can play a key role in creating a clean, reliable energy with substantial environmental and other benefits. For example, a British analysis estimated a reduction of about 41% of CO_2 emissions in 1999 when a combined heat and power (CHP) based DG technology was adopted. In the same vein, a report on the Danish power system, observed a cut of 30% in greenhouse gas emissions from 1998 to 2001, with a widespread of DG technologies [4]. Recently, distributed generation technologies have received much global attention; and fuelling this attention have been the possibilities of international agreements to reduce greenhouse gas emissions, electricity sector restructuring, high power reliability requirements for certain activities, and concern about easing transmission and distribution capacity bottlenecks and congestion, among others.

The main objective of this paper is to examine the environmental benefits of adopting DG technologies in the production of electricity, especially as the demand for electric energy continues to grow on a global level. The structure of the rest part of the paper is as follows: Section 2 presents an overview of distributed energy resources (DER) technologies, while Section 3 focuses on the major environmental impacts of the existing conventional power plants. Section 4 examines the solutions offered by DG technologies in alleviating environmental issues that arise from combustion of fossil fuels for energy production, while Section 5 draws the conclusions of the paper.

2. Distributed energy resources (DER)

Distributed energy resources (DER) refers to electric power generation resources that are directly connected to medium voltage (MV) or low voltage (LV) distribution systems, rather than to the bulk power transmission systems. DER includes both

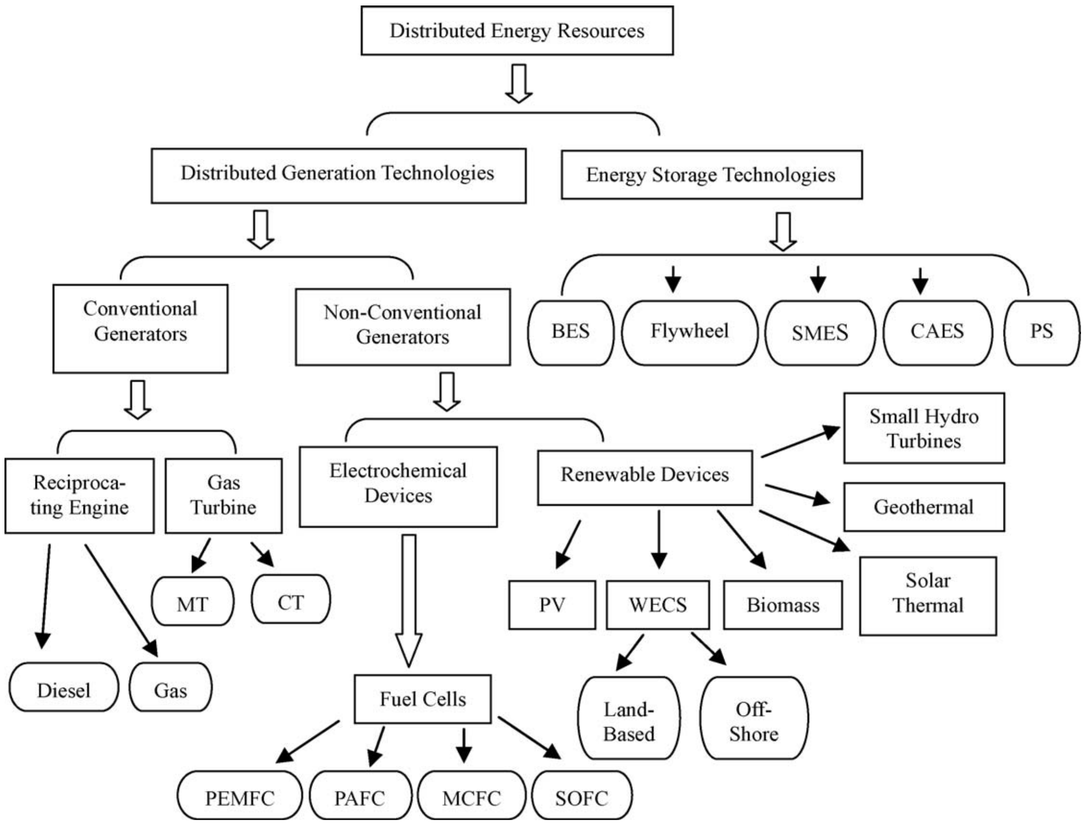

Fig. 2. DER technologies.

generation units such as fuel cells, micro-turbines, photovoltaics, etc., and energy storage technologies like batteries, flywheels, superconducting magnetic energy storage, to mention but a few. Further explanation of each of these is presented in the following sections. Fig. 2 illustrates the technologies that can support DER systems.

2.1. Distributed generation technologies

The exact definition of distributed generation (DG) varies somewhat between sources and capacities; however, it is generally and summarily defined as any source of electric power of limited capacity, directly connected to the power system distribution network where it is consumed by the end users. Really DG is not a new concept in the evolution of electricity industry. DG can be powered by micro-turbines, combustion engines, fuel cells, wind turbines, geothermal, photovoltaic system, etc. DG takes place on two-levels: the local level and the end-point level. Local level power generation plants often include renewable energy technologies that are site specific, such as wind turbines, geothermal energy production, solar systems (photovoltaic and combustion), and some hydro-thermal plants. At the end-point level, the individual energy consumer can apply many of these same technologies with similar effects. One DG technology frequently employed by end-point users is the modular internal combustion engine. Detailed discussion of each of these technologies is considered next in this paper.

2.1.1. Fuel cells (FCs)

Fuel cells convert chemical energy directly into electrical energy and heat. This process could be likened to that of batteries, since they both use electrochemical process, between hydrogen and oxygen to generate a d.c. current. These two devices (batteries and fuel cells) consist of two electrodes, separated by an electrolyte. Eq. (1) shows the overall chemical reaction in fuel cells.

$$H_2 + 1/2O_2 \rightarrow H_2O \tag{1}$$

Fuel cells are generally characterized by the material of electrolyte used. Presently five major types of fuel cells in different stages of commercial availability exist [5]. They include proton exchange membrane fuel cell (PEMFC), alkaline fuel cell (AFC), phosphoric acid fuel cell (PAFC), solid oxide fuel cell (SOFC), and molten carbonate fuel cell (MCFC); even though AFC is not suitable for DG application since they are nearly zero tolerance to CO_2 and CO constituents in the fuel. To obtain a.c. current from fuel cell technology, power conditioning equipment is required to handle the inversion of d.c. current generated by fuel cell to a.c. current that is required to be integrated into the distribution network.

Physically a fuel cell plant consists of three major parts, as shown in Fig. 3: a *fuel processor* that removes fuel impurities and may increase concentration of hydrogen in the fuel; a *power section* (fuel cell itself) which consists of a set of stacks containing catalytic electrodes, generating the electricity; and a *power conditioner* that converts the direct current produced in the power section into alternating current to be connected to the grid [6]. Resulting advantages of this technology are high efficiency, almost at partial load, low emissions, noiselessness as a result of non-existence of moving parts, and free adjustable ratio (50 kW–3 MW) of electric and heat generation. The energy savings result from the high conversion efficiency, is typically 40% or higher, depending on the type of fuel cell. When utilized in a cogeneration application by recovering the available thermal energy output, fuel cell's overall energy utilization efficiencies can be in the order of 85% or more.

2.1.2. Reciprocating engines

The use of diesel and petrol engines in the provision of standby power for commercial and small industrial customers is

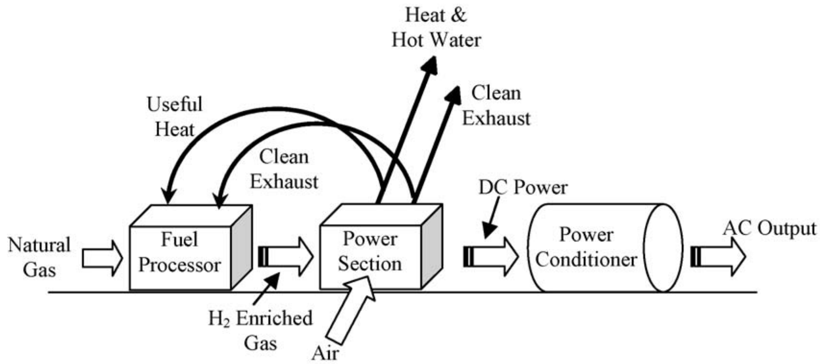

Fig. 3. Fuel cell plant schematic block diagram.

not new. Reciprocating engines, a subset of internal combustion engines, are those engines in which pistons in the cylinders move back and forth. Smaller types are fundamentally designed for transportation, though can be converted with minor modifications to power generators, while larger ones are designed primarily for power generation, mechanical drives, and marine propulsion [7]. Reciprocating engines running on fossil fuels are the first among DG technologies. They are used on many scales, ranging from small units of 1 kVA to large several tens of MVA power plants.

For DG applications, reciprocating engines offer low costs and good efficiency but suffer disadvantages of high emission and high maintenance costs. The improper air–fuel mixtures as well as excessive cylinder cooling produce carbon monoxide (CO), hydrocarbon emissions, while the combustion process generates NO_x. This fact has made sitting of diesel generators extremely difficult visa-a-visa the tightening emission regulation. However, engines operating on natural gas have been developed recently. These engines offer the combination of the efficiency and reliability of a diesel engine with minimal NO_x emissions than its diesel equivalent.

2.1.3. Gas turbines (GT)

A gas turbine, otherwise known as a combustion turbine, is a rotary engine that extracts energy from a flow of combustion gas. It has a combustion chamber in-between the upstream compressor coupled to a downstream turbine. Gas turbines are generally divided into three main categories, namely: heavy frame, aeroderivative, and micro-turbine. The micro-turbines (MT) that are commercially viable are available in the 27–250 kW range. The technology is largely based upon aircraft auxiliary power units and automotive style turbo chargers [8]. Energy is added to the gas stream in the combustor, where air is mixed with fuel and ignited. Combustion increases the temperature, velocity and volume of the gas flow. This is directed through a nozzle over the turbine's blades, spinning the turbine and powering the compressor. Energy is extracted in the form of shaft power, compressed air and thrust, in any combination, and used to power aircraft, trains, ships, generators, and even tanks [9].

2.1.3.1. Micro-turbines (MT). Micro-turbines are becoming widespread for distributed power and combined heat and power applications as they can start quickly. They are one of the most promising technologies for powering hybrid electric vehicles. Generally micro-turbine systems range from 30 to 400 kW [10], while conventional gas turbines range from 500 kW to more than 300 MW [11]. Part of their success is due to advances in power electronics, which enables unattended operation and interfacing with the commercial power grid. Typical micro-turbine efficiencies are between 33% and 37%, especially with 85% effective recuperator [12], but could achieve efficiencies of above 80% in a combined heat and power (CHP) application.

Micro-turbines operate in a similar manner as conventional gas turbines, based on the thermodynamic cycle known as the Brayton cycle [13]. Air is drawn into the compressor via the air inlet pipe as illustrated in Fig. 4. In the compressor, it is pressurized and forced into the cold side of the recuperator, where it is preheated before it enters the combustion chamber. The heated air and fuel are thoroughly mixed together and burnt. It is the mixture, which expands through the turbine that is used to drive the turbine at a speed of 96,000 rpm, since this has been coupled to the shaft of the generator. The generator thus produces high frequency a.c. power that is converted to power frequency by the use of power electronic devices.

Micro-turbine systems have many advantages over reciprocating engine generators, such as higher power density, with respect to footprint and weight, extremely low emissions and few or just one moving part. Those designed with foil bearings and air-cooling operates without oil, coolants or other hazardous materials. Micro-turbines also have the advantage of having the majority of their waste heat contained in their relatively high-temperature exhaust, whereas the waste heat of reciprocating engines is split between its exhaust and cooling system [9]. However, reciprocating engine generators are quicker to respond to changes in output power requirement and are usually slightly more efficient, although the efficiency of micro-turbines is increasing. Micro-turbines also lose more efficiency at low power levels than reciprocating engines.

2.1.3.2. Combustion turbines (CT). The combustion turbines (CT), including heavy frame and aeroderivatives, are typically used in large-scale industrial and utility generation stations starting at the 200 kW–250 MW level per unit [14]. They have been used for power generation for decades. Systems of 15 MW and above are often called utility grade turbines, rotating at a relatively slow

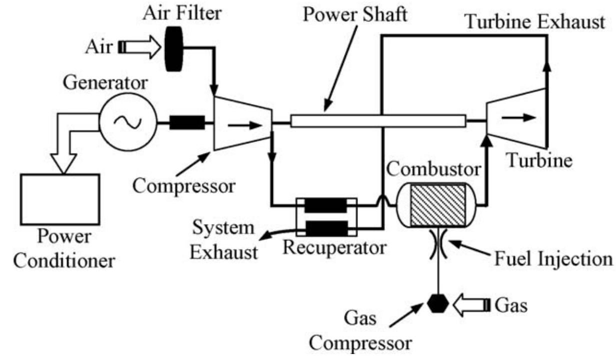

Fig. 4. Basic micro-turbine schematic diagram.

constant speed driving a synchronous AC generator and are considered to be impractical for DG implementation [8]. In view of this, CT is not considered in this literature.

2.1.4. Photovoltaic systems (PVs)

Conversion of solar energy directly to electricity has been technologically possible since the late 1930s, using photovoltaic systems (PVs). These systems are commonly known as solar panels. PV solar panels consist of discrete multiple cells, connected together either in series or parallel, that convert light radiation into electricity. PV technology could be stand-alone or connected to the grid. The output power of PV panels is directly proportional to the surface area of the cells and footprint sizes. Therefore, footprint needs to be relatively large (0.02 kW/m^2). Even though the operating efficiency of this technology may be relatively low (10–24%), nevertheless, it cannot be compared with non-renewable systems. The maximum power output of a PV module is obtained near the knee of its characteristics as shown in Fig. 5.

Since the output current of PVs is a function of solar radiation and temperature, a maximum power point tracking (MPPT) stage is required in the converter to always obtain the maximum power output [15]. PV units are integrated into the grid as depicted in Fig. 6, using inverters, which potentially generate harmonics into the system, although the existing standards seem adequate. However, the effect of multiple inverters needs to be investigated.

2.1.5. Wind energy conversion system (WECS)

Windmills or wind turbines convert the kinetic energy of the streaming air to electric power. Investigation has revealed that power is produced in the wind speed of 4–25 m/s range [7]. The size of the wind turbine has increased rapidly during the last two decades with the largest units now being about 4 MW compared to the 1970s in which unit sizes were below 20 kW. For wind turbines above 1.0 MW size to overcome mechanical stresses, they are equipped with a variable speed system incorporating power electronics. Single units can normally be integrated to the distribution grid of 10–20 kV, though the present trend is that wind power is being located off shore in larger parks that are connected to high voltage levels, even to the transmission system. The power quality depends on the system design. Direct connection of synchronous generators may result in increased flicker levels and relatively large active power variation. At present, wind energy has been found to be the most competitive among all renewable energy technologies. Fig. 7 presents the schematic block diagram of WECS connection to the power grid.

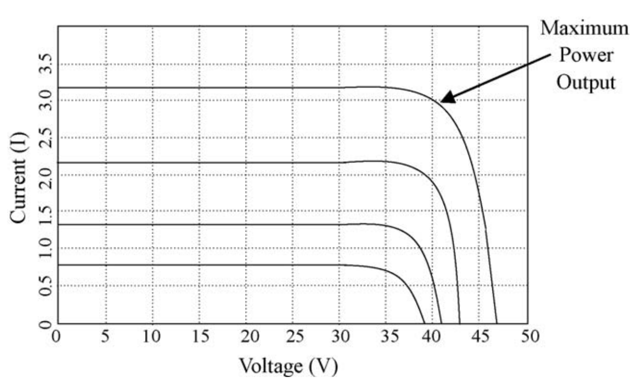

Fig. 5. Typical *V–I* characteristic of a PV module.

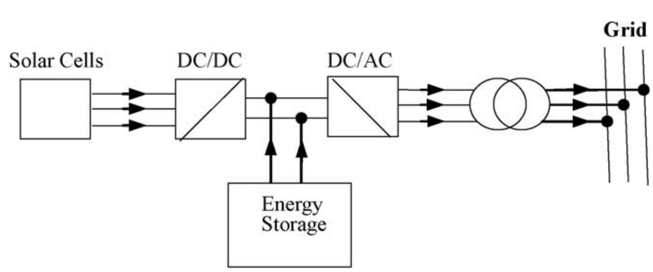

Fig. 6. PV connection schematic diagram.

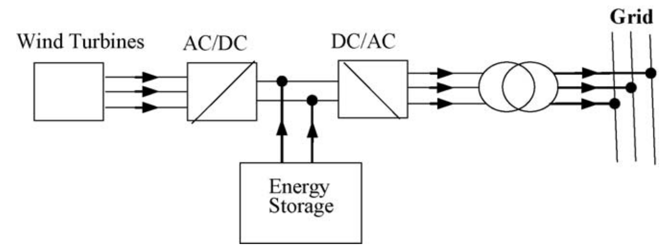

Fig. 7. Wind turbine connection schematic diagram.

2.1.6. Solar thermal

Solar thermal is a technology for harnessing solar energy to produce thermal (heat) energy. To achieve this, parabolic dish systems made of reflective materials such as concentrating mirrors, are used to focus the sunlight on a central vessel containing the working fluid to produce temperatures in excess of 1000 °C, while line-focus parabolic concentrators focus solar radiation along a single axis to generate temperatures of about 350 °C. The resulting high temperatures can be used to create steam to either drive electric turbine generators as shown in Fig. 8, or to power chemical processes such as the production of hydrogen [16].

The USA Energy Information Administration has classified the solar thermal as low-, medium-, or high-temperature collectors. Low temperature collectors are flat plates generally used to heat swimming pools. Medium-temperature collectors are also usually flat plates and are used for creating hot water for residential and commercial use, while high-temperature collectors concentrate sunlight using mirrors or lenses. They are generally used for electric power production. Solar thermal technology has the potential to supply over 90% of grid power, while finding solutions to environmental issues.

2.1.7. Geothermal

Geothermal energy is the heat from the earth. Geothermal power is one of the most exploited renewable energy sources that

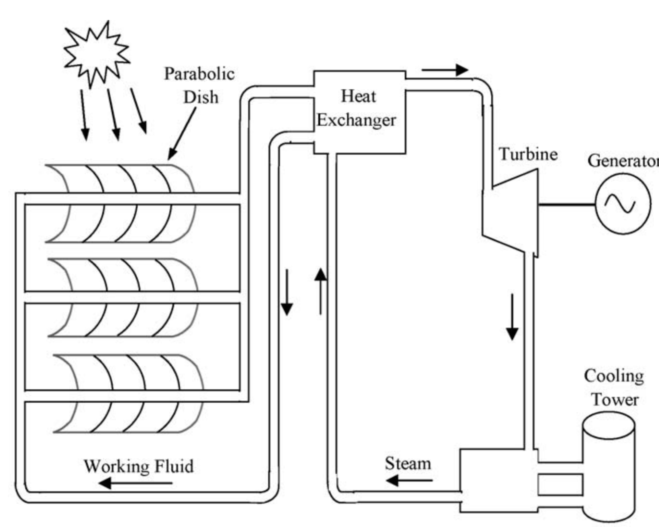

Fig. 8. Schematic diagram of a solar thermal plant.

exist on the planet earth today. It has more than 6000 MW installed generation capacity in 21 countries across the globe [17]. The largest geothermal plant now in operation is found in an area called The Geysers, north of San Francisco. Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the earth's surface, and down even deeper to the extremely high temperatures of molten rock called magma.

A geothermal power plant uses its geothermal activity to generate electric power. To harness the energy, deep holes are drilled into the earth, much like when drilling for oil, until a significant geothermal hot spot is found. When the heat source has been discovered, a pipe is attached deep down inside the hole, which allows hot steam from deep within the earths crust to rise up to the surface. The pressurized steam is then channelled into a turbine, which begins to turn under the large force of the steam as shown in Fig. 9. Since the turbine is coupled to the generator, the generator also begins to rotate, which in turn leads to production of electricity. Cold water is then pumped down a new pipe which is heated by the earth and then sent back up the first pipe to repeat the process.

The first advantage of using geothermal heat to power a power station is that a geothermal system is extremely environmentally friendly, unlike most power stations. Even though it may once in a while, release some gases from deep down inside the earth, which may be slightly harmful, nevertheless, these can be contained quite easily. Again the cost of the land on which to build a geothermal power plant is usually less expensive than the construction of oil, gas, coal, or nuclear power plant would take. Another factor that comes into this is that because geothermal energy is very clean, you may receive tax cuts, and/or no environmental bills or quotas to comply with the countries carbon emission scheme (if they have one). Further, the running costs for the plants are very low as there are no costs for purchasing, transporting, or cleaning up of fuels to generate the power.

However, some of the disadvantages include non-availability of geothermal hot spots in the land of interest. Even when found, the following questions are usually of concern during a survey: is the rock soft enough to drill through? Do the rocks deep down contain sufficient heat? Will this heat be sustainable for a significant amount of time? Is the environment fit for a power plant? If the answer to these basic questions is yes, a more in-depth survey could go ahead. Another big disadvantage of geothermal energy extraction is that in many cases, a site that has happily been extracting steam and turning it into power for many years may suddenly stop producing steam. This can happen and last for around 10 years in some cases [18].

2.1.8. Small hydro-turbines

The terms "small hydro" define installations for the production of hydroelectricity at low power levels. Usually, the power from such installations can be in the range of 5–100 kW for "micro hydroelectric" power stations, and between 500 kW and 10 MW for mini hydro-power stations. The heads of such plants can be in the range of 1.5–400 m with flows ranging from several hundreds of liters per second to several tens of cubic meters per second [6].

In a small hydro-power station the technical electromechanical solutions to be adopted should be robust and as simple as possible to reduce costs and decrease maintenance, assuring profitability of the investments. On the strength of these, the various turbine manufacturers have developed standardized units for small hydroelectric systems. Their designs are based on the following principles: the optimum use of the latest research into turbine machinery; the supply of the electromechanical equipment in a compact ready-to-install and ready-to-operate form; and simple hydraulic design, using standard components to reduce costs and delivery times. This approach is applicable to powers between 100 and 2000 kW [19].

2.1.9. Biomass

Biomass is considered one of the most important energy sources among the renewable energies in near future. Biomass is organic material made from plants and animals. It is a renewable energy source because more trees and crops can always be grown, and waste from them would always exist. Modern biomass energy recycles organic waste from forestry and agriculture, like corn stovers, rice husks, wood waste and pressed sugar cane, or uses special, fast-growing "energy crops" like willow and switchgrass, as fuel. According to the US International Energy Agency, 11% of the world's energy, both heat and power, is currently derived from biomass, with the poorest nations deriving 90% of their energy from it, even though it now accounts for 45% of the renewable energy used in the United States. Some examples of biomass fuels are wood, crops, manure, and some garbage as portrayed in Fig. 10.

The potential of biomass to help meet the world energy demand has been widely recognized. When burnt, the chemical energy in biomass is released as heat, which is used to produce steam that can in turn be used to either drive a turbine for the production of electricity or to provide heat to industries and homes. Combustion of biomass involves burning the biomass in air at a flow rate of 4–5 kg of air per kg of biomass. This process on small-scale is always used for thermal applications, while a large-scale combustion plant with steam cycle is essential for power generation [20].

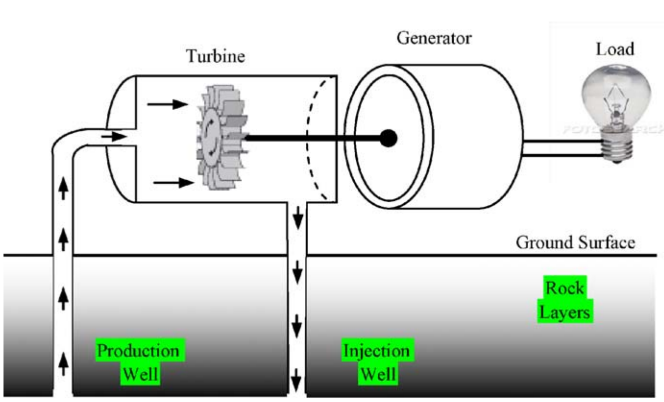

Fig. 9. Dry steam power plant.

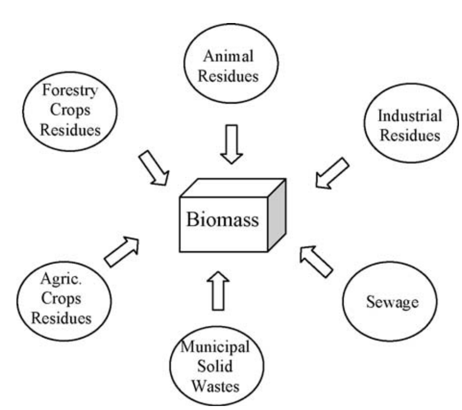

Fig. 10. Biomass sources.

Biomass can as well produce fuel for cars that is dramatically cleaner than oil.

Advantages

- It is a theoretically inexhaustible fuel source.
- There is minimal environmental impact when fermentation, pyrolysis, etc., are used to generate energy instead of the direct combustion of plant mass.
- Alcohols and other fuels produced by biomass are efficient, viable, and relatively clean burning.
- It is available throughout the world.
- Using biofuels in our cars results in less global warming pollution than gasoline.

Disadvantages

- Could contribute a great deal to global warming and particulate pollution if directly burnt.
- Still an expensive source, both in terms of producing the biomass and converting it to alcohols.
- On a small-scale there is most likely a net loss of energy—energy must be put in to grow the plant mass.

2.2. Energy storage technologies

Electric energy production requires the conversion of energy into electricity. However, conversion processes such as solar, wind, and hydro rely on a fluctuating fuel source. In these cases, the power system must have some energy storage capability to overcome the fluctuations in the energy supply. In other cases, energy storage provides a means for harnesses excess energy production, for example utilities produce more excess electricity at night. Energy storage normally occurs through a conversion process from electrical energy to another form of potential energy. Options for large-scale energy storage include battery energy storage (BES), flywheels, superconducting magnetic energy storage (SMES), compressed air energy storage (CAES), and pumped storage.

2.2.1. Battery energy storage system (BESS)

The primary function of the battery energy storage system (BESS) is to provide spinning reserve in the event the power plant or transmission line equipment fails. For these systems, rechargeable batteries are used to store electricity in the form of chemical energy. To meet the energy storage requirements, the battery must be of high energy density, high power, high charge efficiency, good cycling capability, long life and low initial cost. The bulk of existing utility-scaled battery storage systems are made up of large numbers of lead-acid cells, utilizing technology similar to that found in automobile batteries.

Apart from this, other applications where batteries are being considered for utility power systems include load levelling, and in the control of voltage, VAR, and frequency. Batteries provide quick response time; response to load changes occurs in about 20 ms. They are also quiet and non-polluting, making them ideal for installation in suburban areas, close to load centres. The following technologies have been used and/or proposed for energy storage applications [21]: lead-acid batteries, nickel-metal hybride (NiMH) batteries, lithium ion batteries, and lithium polymer batteries. Further explanation of each of these is outside the scope of this paper.

2.2.2. Flywheels

A flywheel is an electromechanical storage system in which energy is stored in the kinetic energy of a rotating mass. It provides about 80% energy efficiency. A flywheel is used to smooth the energy fluctuations in combustion engines and make the energy flow uniform. Fig. 11 shows a schematic diagram of a flywheel energy storage system. The flywheel delivers rotational energy to power an electric generator until friction dissipates it. The energy stored is equal to the sum of the kinetic energy of the individual mass elements that comprise the flywheel. The kinetic energy of a flywheel in Nm (J) is given in Eq. (2)

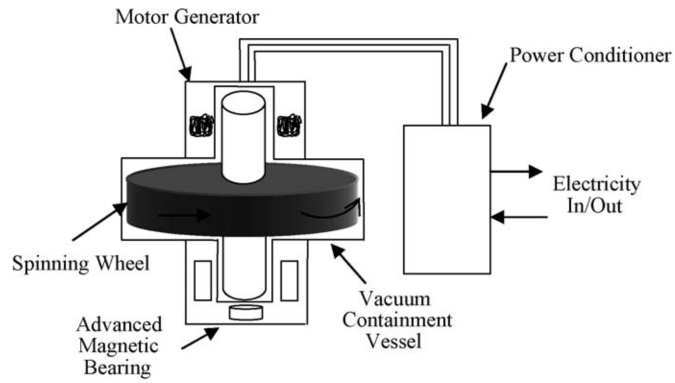

Fig. 11. Flywheel energy storage system.

$$E_{\mathrm{f}} = \frac{1}{2} I \omega^2 \tag{2}$$

where I is the moment of inertia (kg m^2), and ω, the angular velocity (rad/s). The moment of inertia is defined as

$$I = kMR^2 \tag{3}$$

where M is the mass, R is the radius, and k is the inertial constant, which depends on the shape of the object.

The rotor contains a motor/generator that converts energy between electrical and mechanical forms. In the system the rotor operates in vacuum and spins on bearings to reduce friction and increase efficiency. Steel-rotor systems rely mostly on the mass of the rotor to store energy while composite flywheels rely mostly on speed. During charging, electric current flows through the motor increasing the speed of the flywheel, but the generator produces current flow out of the system slowing the wheel down during discharge. To optimize the energy-to-mass ratio, the flywheel needs to spin at the maximum possible speed. For effective storage of energy, long rundown times are required. Using frictionless bearings and a vacuum to minimize air resistance can result in rundown times of 6 months. Flywheel sizes range from 40 kW to 1.6 MW for 5–120 s.

Flywheels are used as uninterruptible power supply (UPS) systems to deliver power protection for critical operations [22]. A growing use for flywheel technology involves frequency regulation on the electricity grid. When integrated into weak grid-connected and autonomous power systems supplied from wind turbines generators and/or other renewable energy sources, flywheel energy storage can provide an effective short-term storage for filtering wind power fluctuations due to wind turbulence and unpredictable load levelling.

Advantages

- Flywheels can store and release large amounts of power very quickly and efficiently when compared to conventional batteries.
- The lifetime and maintenance of flywheel technologies are around 20–30 years and some can operate with no maintenance in that time.
- Flywheels do not suffer from the memory effect, which plagues some types of batteries.

- They can operate under higher temperatures and a wider range of environmental conditions.
- Flywheels are not affected by temperature changes as are chemical rechargeable batteries.
- They are also less potentially damaging to the environment.
- By a simple measurement of the rotation speed, it is possible to know the exact amount of energy stored in flywheels.

Challenges

- The use of flywheel accumulators is currently hampered by the danger of explosive shattering of the massive wheel due to overload.
- One of the primary limits to flywheel design is the tensile strength of the material used for the rotor.

2.2.3. Superconducting magnetic energy storage (SMES)

Another type of energy storage system to consider is superconducting magnetic energy storage (SMES). The SMES is a fast controllable device which can either absorb or supply real and reactive power. This type of energy storage involves converting off-peak power direct current and feeding it to a doughnut-shaped coil of superconducting wire. The coil is installed in a trench and kept at superconductive temperature by a refrigeration system. With this process, the unit can store and discharge energy at an efficiency of greater than 90%, and charges in less than 25 ms [23]. However, this system is very expensive, and some engineering problems related to superconductors must be solved. In addition to these obstacles, SMES contains unknown health effects due to the large magnetic field.

Several reasons are responsible for preferring superconducting magnetic energy storage to other energy storage methods. The most important advantage of SMES is that the time delay during charge and discharge is quite short. Consequently, power is available almost instantaneously and very high power output can be provided for a brief period of time. Other energy storage methods, such as pumped hydro or compressed air have a substantial time delay associated with the energy conversion of stored mechanical energy back into electricity. Thus SMES is the most viable option if a customer's energy demand is to be met immediately. Another advantage is that its power loss is less than other storage methods since electric currents in the system encounter almost no resistance. Lastly SMES could guarantee high reliability since its main parts are motionless.

2.2.4. Compressed air energy storage (CAES)

During off-peak electricity period, CAES plants compress air into an underground reservoir, known as cavern. At peak period when electricity demand is high, the air is withdrawn, heated with gas or oil, and run through expansion turbines to drive a generator. These plants burn about one-third of the fuel of a conventional combustion turbine, thereby producing about one-third the pollutants. Since this process uses an electromechanical converter to produce electricity, the machinery is commercially available. A prominent application of CAES is in wind turbine power plants due to intermittency of wind energy.

Diabatic and adiabatic classes of CAES are available. In a diabatic CAES, air is cooled before it enters the cavern and reheated before it is expanded in a modified gas turbine process. The first of such plant was built in 1978 in Germany, with a capacity of 290 MW [24]. On the other hand, the air's heat energy is stored separately and recovered before the compressed air is expanded in an air turbine in an adiabatic CAES. Such plants are currently under development and promise higher efficiencies and zero direct CO_2 emissions [25].

2.2.5. Pumped storage (PS)

Like CAES, pumped hydro-facilities use off-peak electricity to pump water from a lower reservoir into one at a higher altitude. When the water stored in the upper reservoir is released, it is passed through hydraulic turbines for production of electricity. The off-peak electrical energy used to pump the water up hill can be stored indefinitely as gravitational energy in the upper reservoir. Thus, two reservoirs in combination can be used to store electrical energy in large quantities for a long period of time. Pumped storage is the largest capacity form of grid energy storage now available. Pumped hydro-energy storage can be used to smooth out the demand for base load generation from hydroelectric plants since frequent switching of large power stations on and off is an inefficient way to run them. Basic advantages of pumped storage include low cost power, frequency regulation of the grid, and reserve capability are provided when the water is released through a turbine during peak demand periods.

3. Environmental impacts of the conventional power plants

3.1. Raw fuel production

Today, the primary energy source of most centralized power plants on a global level is fossil fuels, majorly coal. For example, presently more than 80% of China's electricity generation is from fossil fuel combustion [26]. Coal is almost exclusively produced as fuel for generation of electric energy [4]. Coal production on its own, constitutes a local environmental problem, as it has both long-term and short-term effects on land and aquatic inhabitants. In the case of nuclear power plant, environmental degradation starts from the mining of its raw materials. Radioactive dust releases as well as toxic metal and chemical wastes are a serious threat to the environment. Transportation of the fuel is another source of hazard which calls for concerns, as there are possibilities of accidental release of radioactive particles to the atmosphere; which could result to loss of life and render the area around the plant uninhabitable.

3.2. Generation of electricity

For over 100 years now, energy and power production have been generated around the world through the burning of fossil fuels, of which coal has the lion share. The USA Energy Information Administration has estimated in 2005 that fossil fuels burning constitute 86% of the world primary energy production, with the remaining non-fossil fuels being hydroelectric (6.3%), nuclear (6.0%) and others (geothermal, solar, wind, etc.) 0.9% [27]. Since coal has the highest carbon intensity among fossil fuels, it is expected that coal-fired plants would generate the highest output rate of CO_2 per kW h. In the United States, for example, about 40.5% of anthropogenic CO_2 emissions were attributed to the combustion of fossil fuels arising from generation of electricity in 1998. In 1999, estimated emissions of CO_2 in the United States resulting from the generation of electric power were 2245 million metric tonnes. This is an increase of 1.4% from the 2215 million metric tonnes of 1998, out of which 1788 million metric tonnes were from coal-fired plants alone [28]. Analyzing this means that emissions of CO_2 from coal-fired power plants constitute almost 80% of the total CO_2 emissions produced by the generation of electricity in the United States, while the share of electricity generation from coal was 51.0% in the same year.

Fig. 12 presents a projection of annual global anthropogenic GHG sources by economic sectors, for the next 100 years. As a sector, power generation has the highest production of CO_2 emissions [26,29,30]. This is because fossil fuels still form substantial part of its primary source of energy. Fig. 13 is the

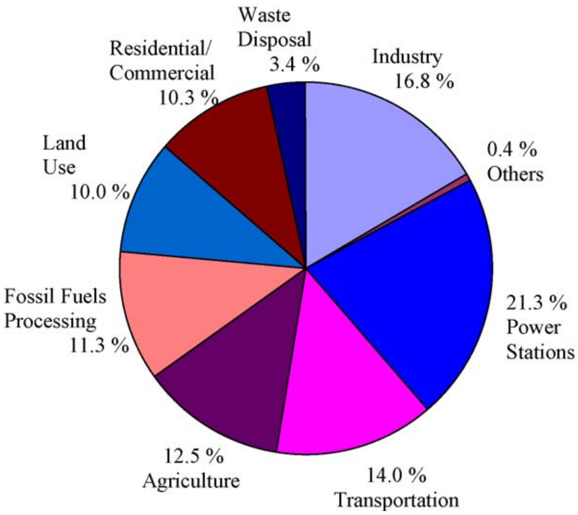

Fig. 12. Annual global anthropogenic GHG emissions by economic sector.

emissions characteristics of some DG technologies relative to a coal-fired plant [31]. From the figure, it could be seen that coal-fuelled plant is the major contributor of CO_2 and SO_2 emissions. Certainly, numerous health and ecological problems could result from these emissions. For example when SO_2 dissolves in the atmospheric moisture, the result is acid rain. Acid rain is known to be a serious environmental issue as acidification of Scandinavian lakes in the 1970s is a case of reference [32].

3.3. Transmission of electricity

The conventional power plants involve the generation of electricity at a remote area, and transmission of this power over long transmission lines to the load centre. These lines are viewed to cause some aesthetic nuisance to the environment. They could cause communications interference, and can equally pose hazards to low flying aircrafts. Another major issue on these lines is the amount of electromagnetic radiations they emit as current flows in the line conductors, which are of concern to human health. It is revealed that the magnetic field directly underneath a transmission line is in the range of 300 and 600 mG and has a field strength of between 10 and 100 mG at some 61 m away [4]. An investigation made by Draper et al. [33] shows a 70% increase in childhood leukaemia for those living within 200 m of an overhead transmission line, and a 23% increase for those living between 200 and 600 m, both of which are statistically significant.

In the same vein, the post-1979 property-value studies show that there is a decline in market values of about 5–10% of the properties adjacent to transmission lines [34]. This necessitates electric utilities in the US to pay compensation estimated to the tune of more than 5 billion USD to the property owners for the damages.

4. Using DG technologies to alleviate environmental problems

There are a number of benefits that can be derived from DG adoption in power systems, this paper will however, focus on the environmentally related ones. In the literature, there are four major environmental benefits related to the adoption of DG technology. First, DG promotes higher energy efficiencies. This is possible since some DG technologies can support cogeneration systems. Secondly, DG reduces the greenhouse gas emissions emanating from generation of electricity. Again, DG minimizes the health risks, and lastly conserves more resources for better additional use. Each of these is further expatiated in the following sections.

4.1. DG promotes higher energy efficiencies

Power generation systems produce large amounts of heat in the process of converting fuel into electricity. More than two-thirds of the energy content of the input fuel is converted to heat, and the heat is usually wasted in many conventional central generating

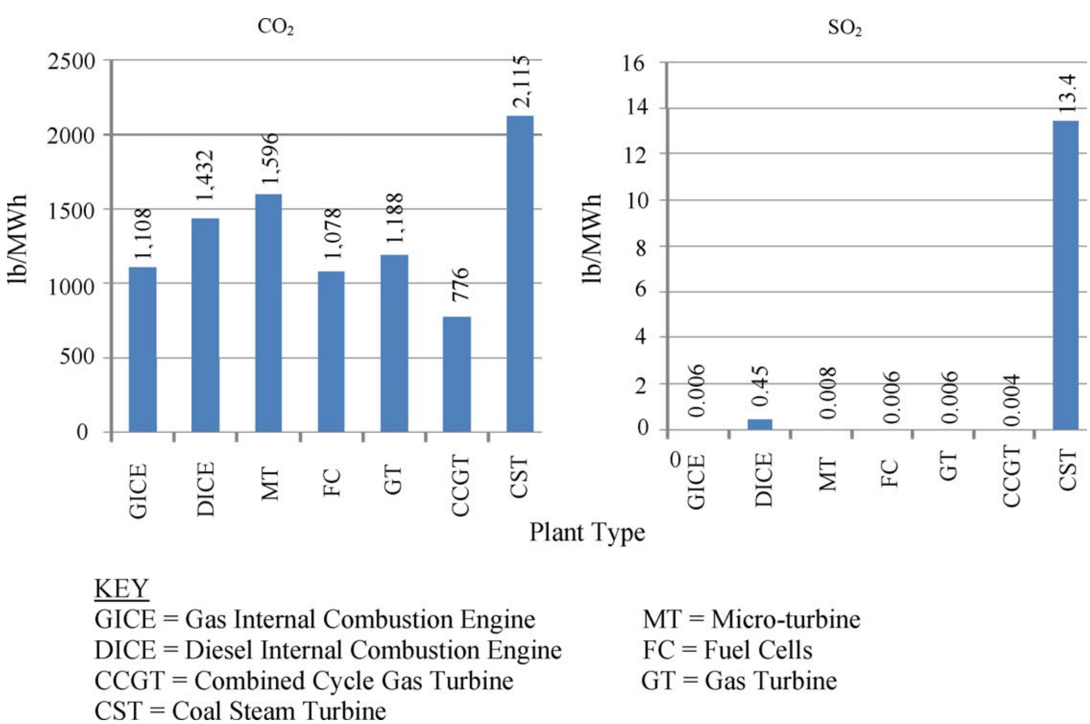

Fig. 13. Emissions comparison of DG and centralized technologies.

plants. As an alternative, an industrial user with significant thermal and power needs can generate both energies in a single combined heat and power system located at or near the site of consumption. Most distributed generation technologies considered for the commercial sector provide useful heat as well as electricity, providing the potential for use as combined heat and power (CHP) systems. This has a potential to raise total system efficiencies up to 90% in the best applications [29]. In the EU-15, the percentage of electrical energy produced by CHP-based DG in year 2000 accounted for almost 10% of the total electricity generation in the region, i.e. 250,000 GW h of the total of 2,600,998 GW h [35]; with Germany topping the list, followed by Netherlands.

The capture and use of heat to satisfy water and space heating needs often make CHP systems more economically attractive than systems that are used exclusively for electricity generation. When compared to separate fossil-fired generation of heat and electricity, CHP, depending on its size and efficiency of the cogeneration units, can result in primary energy conservation, ranging from 10% to 30% [36,37]. Consequently, the emission reductions are in a first approximation similar to the amount of energy saving. Presently, depending on the displaced heat sources and electricity, the savings can be up to 1000 tonnes of CO_2 per GW h of power production. Apparently now, nothing less than 200 million tonnes of CO_2 is annually avoided by operating CHP plants [38].

Hadley and Van Dyke [39] compare the reduction in existing system emissions to the ones generated from DG to determine the net savings. It is found that with DG installed on the system, there is production of electric energy with minimal greenhouse gas emissions and other pollutants to the atmosphere, when compared to the conventional technologies. Chiradeja and Ramakumar [40] formulated environmental impact reduction index (EIRI), the result of which clearly showed that DG significantly reduce pollutant emissions; even though the impact depends largely on DG rating. Similarly, nine cogeneration projects feeding on bagasse, in contrast to fossil fuels, were used for generation of electricity in some Indian sugar mills. The size of cogeneration plants which ranged from 12 to 24 MW, with a total capacity of 200 MW, helped India to reduce her CO_2 emissions by more than 550,000 tones annually [41]. This proven success achieved in these projects will help India achieve the estimated 5000 MW potential of bagasse cogeneration she has.

Further in [42], it is demonstrated that 65 million tones of CO_2 can be saved per annum, on European scale, with 50 million of CHP units' installation. Also, some selected Portuguese networks of various types, ranging from LV to HV networks have recorded a reduction in CO_2 emissions by approximately 2.1–4.9% with 20% penetration of distributed generation [43].

4.2. Reduction in greenhouse gas emissions due to power generation

Distributed generation technologies have received a great deal of attention from the energy community due to a number of reasons. One of these is regarding their potential to save energy, increase the reliability of electricity supply, and decrease the cost of upgrading the existing electrical grid. Another reason for this growing activity is their benefits of low greenhouse gas emissions since they can use clean energy sources, other than fossil fuels. For example, photovoltaic generation produces less than 15% of the carbon dioxide a conventional coal-fired power plant would produce [44]. A study has shown that a 2-kW photovoltaic system in Montana will avoid emissions of 0.68 lbs of NO_x and 3643 lbs of CO_2, which is found to be equivalent to reducing carbon dioxide emissions equal to driving 4553 miles in an average passenger car. By so doing, one is able to achieve a reduction in the carbon dioxide emissions equal to the carbon dioxide absorbed by 1 acre of trees in 1 year. Further, a 9% reduction of CO_2 emissions was achieved using

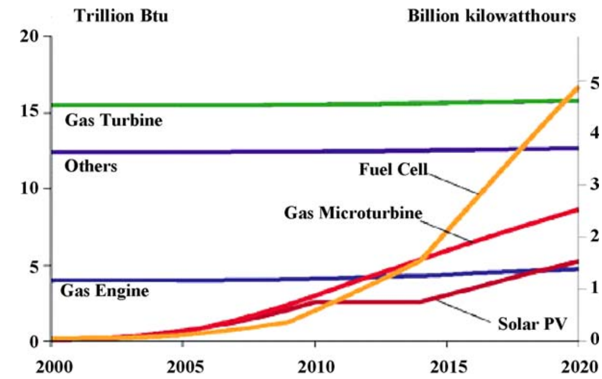

Fig. 14. Projected electricity generation by selected DG sources.

forecasted approach [45] when 800 MW capacity of wind generation (representing over 11% of the national installed capacity) was installed on Ireland power system.

Furthermore, another study has revealed that using solar energy to supply a million homes with energy would reduce CO_2 emissions by 4.3 million tonnes per year. This amount is calculated to be equivalent to removing 880,000 cars from the road [46]. Fortunately clean renewable energy sources can help meet the rising energy demands, as illustrated in Fig. 14, obtained from AEO2000 National Energy Modelling System, where the use of distributed generation technologies is projected through 2020. Some scientists and industry experts have estimated that renewable energy sources, such as solar, can supply up to half of the world's energy demand in the next 50 years, even as energy needs continue to grow. Focusing on and harnessing these energy sources would enable us to rely less on fossil fuels in the generation of electricity, thereby reducing the overall greenhouse gas emissions.

4.3. Minimizes damage to health

Distributed generation technologies are able to mitigate climate change and consequently reduce health risks to the society. DG is capable of achieving this goal in two ways. One, the value of reducing the reliance on the central grid enables less power losses, and hence less power is produced from the conventional plants. Two, the pattern of emissions from outdoor or airborne pollutants such as NO_x, SO_2, and others from clean DG units are less hazardous than emissions of the conventional plants that DG replaces. Due to these two factors, the quality of air is being conserved from man-made pollutants, which in turn means reduction in health damage. In addition, since less power would be transported over transmission lines when DG is fully adopted, there is a reduced public concerns over health risks such as leukaemia and brain cancer [33,34] caused by electromagnetic radiation.

4.4. Space advantage

Another major environmental benefit of DG technologies is that fewer natural resources are used in the production of electric power, relative to the conventional systems. Energy industry researchers have estimated that the amount of land required for photovoltaic (PV) cells to produce enough electricity to meet all US power needs is less than 60,000 km^2. This is roughly 20% of the area of Arizona [46]. PV panels can be integrated into building surfaces for the generation of electric power, thereby eliminating additional land use. For example, the 30,480-m^2 roof of a typical discount retailer could produce more than a megawatt of solar electricity. Solar and wind energy systems need less space to produce a megawatt of electricity than coal-fired power when the land

devoted to mining of its fuel is put into consideration. The land saved from this could be used for another purpose.

5. Conclusions

An overview of distributed energy resources (DER) technologies has been presented in detail in this paper. The study examined the environmental impacts of the conventional power generation method feeding on fossil fuels to the detriment of our environment. It thereafter identified four areas where DG could be of significant use in mitigating these environmental problems, thereby improving the air quality. The areas are: reduction in GHG emissions, higher energy efficiencies, reduced damages to human health, and conservation of resources for additional use.

Conclusively, in view of the tremendous environmental impact of the conventional power plants, as evident in this literature, it becomes imperative to rely less on them for generation of electricity especially. Finding another energy sources such as distributed generation that feed on renewable energy sources would not only help meet the growing energy demand but also preserve our environment from the devastating effects of GHGs caused by the traditional method. Interestingly, scientists and experts in industries have estimated that the available renewable energy sources can meet the requirement of the future global energy demand.

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